voluntary examinations depending on age or special needs. Examinations were comprehensive and included standard components such as history and physical, hearing test, laboratory studies (blood and urine), chest x-ray, cardiogram, and eye examination. Later on, more sophisticated studies, such as pulmonary function, comprehensive blood chemistry studies, and glaucoma testing, were added to the protocols. Along with the promulgation of industrial standards and regulations, medical surveillance requirements for regulated substances (such as asbestos) and medical approval for persons working in potentially hazardous situations requiring respirator use were incorporated into the medical program.

Employee medical records have been retained locally for most former and current PGDP employees. Some exceptions include employees who may have been transferred to other Federal facilities or a few records that may have been misplaced or lost. The medical records contain the results of all physical examinations, personal and occupational treatments rendered by the medical staff, major medical insurance records, and all work-related incidents or accidents that required medical intervention. Of special interest are the incident/accident reports, especially from the 1950s and 1960s, that chronicle the nature and extent of worker exposures to process gas, HF acid, and welding injuries.

It was evident from interviews and the review of official PGDP publications, such as the AEC quarterly report, that medical personnel were aware of and concerned about the long-term effects of exposures to chemicals and radiation; however, physical examination results did not appear to discuss or target those concerns. Quarterly reports document that no major long-term health effects from these exposures have appeared in the Plant population. Similarly, very little exposure information was included in any individual medical record, but interviews with former medical personnel indicate that exposure information was available if needed by the physician.

Several former workers noted during interviews that in the 1950s and 1960s, some employees working in or near hazardous operations did not receive the required medical examinations. For example, machine shop employees working in C-720, adjacent to the compressor maintenance shop, reported that although they may have been routinely exposed to process gas and contaminated dust, they were not required to have protective equipment or participate in mandatory medical examination programs. This failure to recognize and monitor some obvious worker exposure groups was not explained by either the former workers themselves or documents available to the team.

Personal medical care for employees has always been important in the PGDP medical program. Many employees utilized the medical care available at the Plant to supplement the available resources in the community. It appeared that keeping workers healthy and productive at work was an important consideration for the medical staff, resulting in many personal visits to the dispensary for advice, medications, and treatment. It was also obvious from interviews that some employees considered routine exposures to gases and chemicals insignificant and simply part of their normal work routine. Therefore, they did not report minor skin irritations, congestion, nosebleeds, eye irritation, and other indicators of possible long-term health effects.

Identification of physical hazards received greater focus in the Plant's early history than did identification of hazards that resulted in an exposure. However, there were a few exceptions, such as noise, uranium, fluorides, and dust. Recording and trending of injury data, which began in the second quarter of 1953, continue today. Early recorded statistics included man-hours worked, number of minor and disabling physical injuries (e.g., cuts and burns), and man-days lost. The rates of both frequency and severity of injuries were calculated from the beginning of the Plant's history. (Illness statistics were not compiled until after the 1970s.) In the 1950s, the Health Physics and Hygiene Department quarterly reports typically identified 40 to 60 workers per quarter seeking medical attention as a result of accidental releases of uranium, hydrogen fluoride, and fluorine. In the second quarter of 1955, accidental releases of toxic material within the Plant were considered "minor" since "only 12 men reported to the dispensary for medical attention." The 1961 Paducah Operations Training Manual compared injury rates at Paducah to injury rates at common industrial sites (e.g., coal mining and lumber jacking). Although Paducah's disabling injury rate compared favorably, such was not the case for Paducah's injury severity rate.

3.2 Operations and Maintenance

Operations and maintenance activities are described below, as well as the effectiveness of controls to protect workers, the public, and the environment from hazards. In addition, Appendix B summarizes the principal hazardous activities conducted at PGDP during the period 1952 to 1990 and provides an assessment of the hazards presented by these activities, the controls used to mitigate the hazards, and the effectiveness of the controls.

- *Feed Plant Operations*
- *Cascade Operations*
- *UF_4 and Metal Production*
- *Recovery Operations*
- *Smelting*
- *Maintenance*
- *Summary*

3.2.1 Feed Plant Operations

In order to enrich the uranium in the cascades, the feed product has to be in the form of UF_6. PGDP currently receives UF_6 directly from various customers. Before 1976, however, much of the uranium was received from the various ore processing refineries and reactor uranium recovery facilities (Savannah River and Hanford) in the form of UO_3, also commonly known as "yellow powder" or "yellowcake." This material was then converted to UF_6 by a three-step reaction process in the C-410/-420 feed plant, which operated from July 1953 through June 1964 and from July 1968 through June 1977. In the first step, the UO_3 was reduced to uranium dioxide (UO_2) by reacting with hydrogen (H_2). The UO_2 was then reacted with HF to produce UF_4, also commonly known as "green salt." The UF_4 was finally converted to UF_6 with fluorine (F_2).

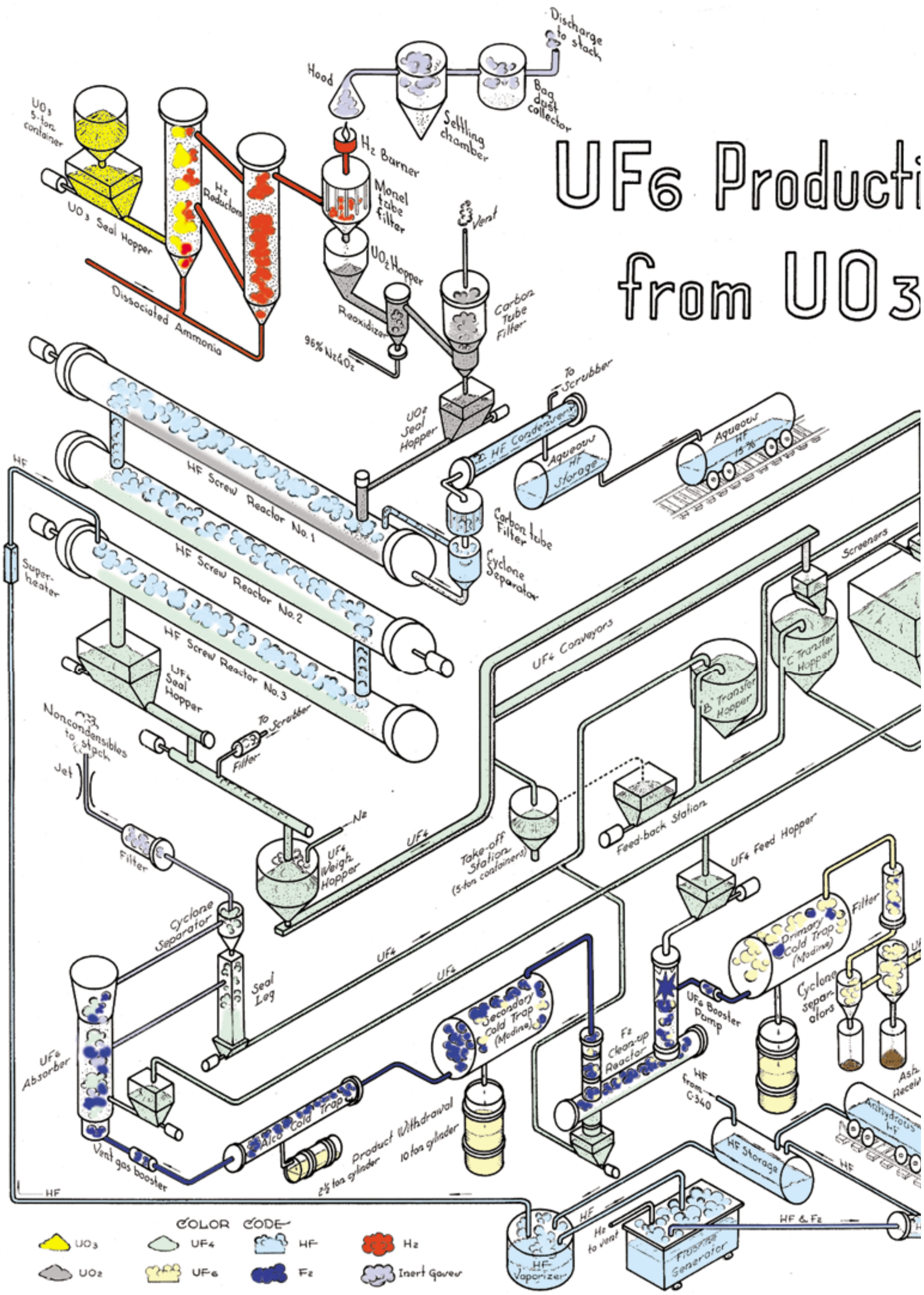
Operating procedures and personnel interviews indicate that the operating and maintenance practices in the feed plant were generally consistent with accepted industrial practices at the time, although the work environment was harsh. From the feed plant startup in 1953 until 1956, there were three lines for processing UO_3 to UF_6 located in C-410. In each line, the first two steps of feed production (green salt production) were conducted on vibrating tray reactors (shaker trays): a 15-foot-long tray for UO_2 production and two 40-foot long trays for UF_4 production. Each line contained a fluorination tower for converting green salt to UF_6 gas. Unexpected harmonic stresses on the trays resulted in frequent failures of the trays and bellows, with subsequent spills and leaks of uranium powders and gases, thereby contributing to the harsh working environment. These failures, combined with increased demand for feed, resulted in the addition of five more fluorination towers and the C-420 green salt feed plant, which replaced the shaker trays with screw reactor and fluid bed technologies. These technologies also had their share of problems. Room temperatures in the feed plant were usually in excess of 100 degrees Fahrenheit, noise levels were high, and leaks in all systems were common throughout the life of the plant.

Exposure to uranium powder dusts was prevalent in both operations and maintenance activities. For example, plugging of conveyers, hoppers, and screws with UO_3 or UF_4 routinely required physical agitation with sledgehammers or metal rods. In many cases, shear pins or chains on the associated drive mechanisms broke, requiring operations personnel to clean the product out of the jammed equipment and maintenance personnel to disassemble and repair the equipment.

The concentrations of uranium daughter products, transuranics, or fission product impurities in the incoming bulk reactor recycle uranium were quite low. However, in certain areas of the feed plant, these materials tended to concentrate to appreciable levels. These areas included the plant dust collection systems, the fluorination towers, and the ash receivers downstream of the fluorination towers. Vacuum and ventilation system bag rooms exposed workers to fine particle dust containing appreciable concentrations of the impurities. The impurities plated out on the inside of the fluorination towers, making them radiation areas and creating intense beta radiation fields when opened for maintenance or unplugging operations. The ash resulting from the fluorination of the UF_4 contained the most radioactive impurities and was sometimes in the form of small

CHEMICAL REACTIONS FOR CONVERSION OF URANIUM TRIOXIDE TO URANIUM HEXAFLUORIDE

- UO_3 (yellowcake) + H_2 (gas) $\longrightarrow$ UO_2 (black powder) + H_2O (steam) (1050°F)
- UO_2 + 4HF (gas) $\longrightarrow$ UF_4 (green salt) + $2H_2O$ (steam) (500 – 1200°F)
- UF_4 + F_2 (gas) $\longrightarrow$ UF_6 (gas) (2000°F)


UF6 Producti
from UO3
Discharge to stack
Hood
Settling chamber
Bag dust collector
UO3 5-ton container
UO3 Seal Hopper
H2 Reductors
Dissociated Ammonia
H2 Burner
Monel tube filter
UO2 Hopper
Reoxidizer
95% N2 & O2
Vent
Carbon Tube Filter
UO2 Seal Hopper
To Scrubber
HF Condenser
Aqueous HF Storage
Aqueous HF 15%
Carbon tube Filter
Cyclone Separator
HF Screw Reactor No. 1
HF Screw Reactor No. 2
HF Screw Reactor No. 3
Super-heater
UF4 Seal Hopper
Noncondensibles to stack
Jet
Filter
To Scrubber
N2
UF4 Weigh Hopper
UF4 Conveyors
Screeners
B Transfer Hopper
C Transfer Hopper
Take-off Station (5-ton containers)
Feed-back Station
UF4 Feed Hopper
Cyclone Separator
Seal Leg
UF4
UF6 Absorber
Secondary Cold Trap (Modine)
Primary Cold Trap (Modine)
Filter
Cyclone separators
UF6 Booster Pump
F2 Clean-up Reactor
HF from C-340
Alco Cold Trap
Product Withdrawal
10 ton cylinder
2½ ton cylinder
Vent gas booster
HF Storage
Anhydrous HF
HF
HF Vaporizer
H2 to vent
HF & F2
Fluorine Generator
COLOR CODE
UO3
UF4
HF
H2
UO2
UF6
F2
Inert Gases

particulates. As a result, the ash receivers provided one of the highest potentials for exposures to workers. Ash receivers were hot and fuming, and at least one full ash receiver usually needed changing out each shift. In addition, plugging of towers with ash frequently required physically challenging manual cleanout, putting workers in close proximity to the towers and the ash plugs for long periods of time. Review of procedures and training records indicates that respirators were typically required for most of this work. However, information from interviews indicated that compliance with these requirements was not always consistent, and compliance with respiratory protection requirements appeared to decline after the feed plant restarted in 1968. In particular, respirator fit problems increased, and the use of respirators tended to decrease during work involving strenuous physical exertion such as clearing plugs in towers, changing out ash receivers, and bag house maintenance. At times, the pressure of the feed production schedule also had a negative effect on respirator use.

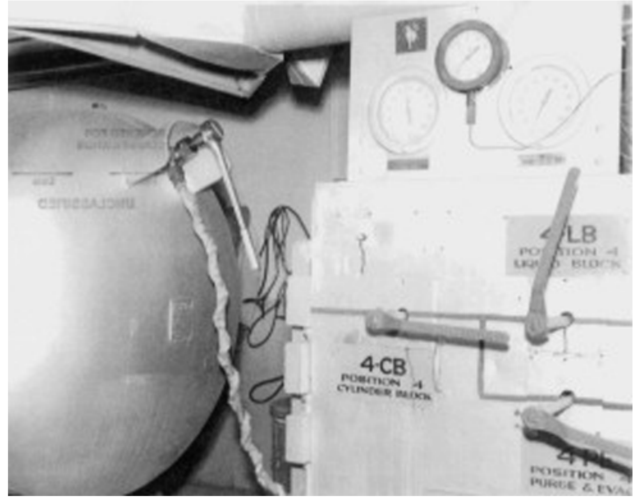
3.2.2 Cascade Operations

- *Product Feed and Withdrawal*
- *Puffs*
- *Jetting and Midnight Negatives*

Product Feed/Withdrawal

The cascades generally operated below atmospheric pressure, and therefore, any leakage consisted of air flowing into the process. The cylinder feed system and the product withdrawal system operated above atmospheric pressure. Any leakage in these areas resulted in process gas venting into and contaminating the surrounding atmosphere. In addition, the "heels" in empty cylinders brought to the withdrawal areas or removed from the feed areas were a source of penetrating radiation for the workers. Cylinder heels are composed of non-volatile corrosion products, uranium salts and oxides, and residual transuranic and uranium daughter product compounds when UF_6 is fed to the cascade. Without the self-shielding effects of the uranium in a full cylinder, the empty cylinders produced appreciable gamma fields. Since cylinders were re-used for five-year periods between cleaning and testing, heels in some cylinders accumulated significant radiation sources.

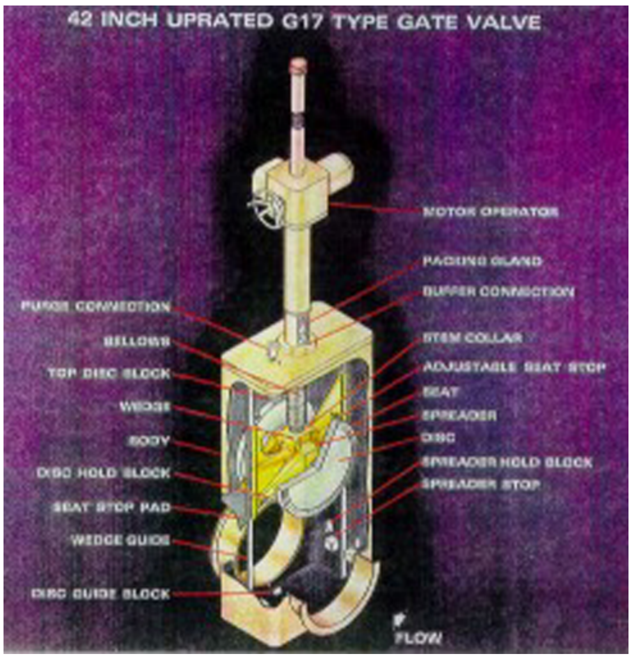
During the 1950s, UF_6 gas was pressurized for feeding to the cascade by heating the cylinders in warm water baths; the water baths had minimal engineered safety features. In November 1960, a cylinder was valved into the cascade before the water bath was fully heated, resulting in backflow into the cylinder from the cascade and an overfill condition. When the inappropriate valving was discovered, the cylinder isolation valve was closed. As the water bath continued to heat the cylinder, the cylinder overpressurized, rupturing the cylinder and releasing approximately 6,800 pounds of uranium.



Cylinder Filling Operation

In the early 1960s, the water baths were replaced with autoclaves, principally located in Buildings C-333A and C-337A, with each building containing several autoclave feed stations. Each autoclave served as a containment boundary in case a leak developed and was equipped with appropriate alarms, indicators, valves, and a remote cylinder valve closure device. Prior to connection to the cascade, each UF_6 cylinder was inspected for damage and confirmed to be safe for use. If a cylinder was found to be defective, it was tagged and moved aside for special handling. Following inspection, a heat traced copper pipe (pigtail) was attached to the cylinder valve and to a corresponding connection within the autoclave, the cylinder valve was opened, the autoclave was closed, and the various alarms were tested. Once the connection integrity and feed path clearance were confirmed, steam heat was initiated to vaporize the UF_6 and began feeding it to its corresponding assay point in the cascade. A UF_6 release within an autoclave would actuate an automatic emergency shutdown and autoclave isolation to protect workers and the environment.

Enriched and depleted UF_6 gas was withdrawn in Buildings C-310 and 315, respectively. Product (enriched UF_6) and tails (depleted UF_6) were withdrawn from the cascade by pumps that discharged through a condenser, piping, and cylinder pigtails to the intended receiving UF_6 cylinder. Product cylinders were not supposed to be filled to more than 95 percent (liquid) of capacity. Those that were overfilled were tagged and subject to special handling to resolve the overfilled condition. UF_6 cylinders still containing liquid could not be transported around the site without special consideration. Before solid UF_6 cylinders were moved to storage, they were "burped" of light gases through sodium fluoride (NaF) traps.



Gate Valve

One ex-operations supervisor reported that operators turned up "hot" in the product withdrawal area more than any other area of the cascade. Portions of the product withdrawal system operated at approximately 30 psig. As a result, small leaks in this area released enriched process gas into the room atmosphere and provided a higher potential for an intake. Air monitor sampling indicated moderately high activity readings for the withdrawal room from initial operations up through the early 1960s. Subsequent increased attention to repairing leaks and improving the ventilation systems led to low activity readings in the room by 1964. Other than a few specific high readings due to leaks, general area air monitoring samples remained low.

Accidental UF_6 releases during the connection and disconnection of cylinders was one of the leading causes of individuals reporting to the dispensary for medical attention in 1953, according to a PGDP quarterly report. It was reported that UF_6 releases often occurred when burping recently-filled UF_6 cylinders. Workers generally wore full-face respirators during this activity and received monthly bioassays. Interviewees recalled at least one instance of a worker attempting to move a product cylinder that was still connected to its pigtail, resulting in a major UF_6 release. Workers reportedly received skin burns while attempting to isolate the release. Interlocks were subsequently added to prevent a recurrence.

Puffs

Puffs are minor releases of UF_6 from process gas equipment and were a common occurrence, despite efforts to minimize the amount of material available for release. Frequently, solid UF_6 deposits became isolated from the process gas stream in closed-end volumes, such as instrument lines, that developed blockage. One instrument mechanic estimated that puffs occurred weekly in the late 1970s. He described frequent puffs on opening process gas systems, despite work permits indicating that the systems contained no UF_6 ("UF_6 negatives"). In some cases, this may be explained by UF_6 freeze-out blockage of sample lines. He described the classic white cloud release, losing his breath, backing away to let normal exhaust ventilation disperse the cloud, and returning to work without special monitoring or cleanup.

An incident was reported in the C-310 product withdrawal building where an instrument heater control malfunctioned, melted tubing solder, and initiated a significant release that filled C-310 and was working its way across the bridge to C-331. Mechanics were reportedly sent without PPE to shut doors in the bridge. The original instrument line leak was secured by crimping the line by another worker outfitted in a Gra-Lite suit. Reportedly there was no special monitoring of the involved individuals, and work resumed after the cloud dispersed.

Operators in the late 1970s and early 1980s reportedly did not typically wear respirators while sampling cascade process gas, despite frequent whiffs and puffs of UF_6. Puffs were frequently experienced in product feed and withdrawal areas when UF_6 cylinder pigtails were disconnected. One interviewee recounted pressurizing offline cascade equipment with UF_6 to "smoke" the cell and detect leaks. He did not recall respirators being worn for this activity. Workers interviewed recall respirators being available, but not being required to wear them; workers' experience helped them determine when a job might produce a puff and, therefore, whether a respirator should be worn.

Jetting/Midnight Negatives

Jetting is the process of purging isolated process gas system equipment of UF_6 and HF by introducing dry air or nitrogen and removing the resulting gaseous mixture with the process building purge jets. Each jet took a suction on its process building evacuation header, which consisted of a two-stage Venturi supplied with 100-pound air, and discharged the resulting gaseous mixture to the environment from an unmonitored open pipe on the process building roof. The jets were intended to evacuate atmospheric air from isolated process gas system equipment in preparation for startup and the introduction of UF_6, and for performing HF sweeps of isolated process gas system equipment once the UF_6 concentration had been reduced below 10 ppm (UF_6 negative) in preparation for opening the process gas system for maintenance, inspection, or parts retrieval. Assuming that the jets were only used as prescribed after a satisfactory UF_6 negative was achieved, less than one-fifth pound of UF_6 was available for release to the environment from a single cascade cell each time. The number and frequency of these authorized releases were not determined.

"Midnight negatives" refers to using the jets at night to accelerate the attainment of an adequate UF_6 negative to support a planned opening of isolated process gas equipment. Depending on the pressure, temperature, and concentration of UF_6 in a cascade cell when jetting was initiated, and assuming that the concentration had been reduced by at least one-tenth through purging and evacuation pumps, up to several thousand pounds of UF_6 could still have been available for release to the environment from a single cascade cell. As with normal jetting, the UF_6 gas would hydrolyze with moist air to form UO_2F_2 powder and HF gas. The number and frequency of these inappropriate releases were not determined during this investigation.

Some current and former operators were aware of rumors about or participated in midnight negatives. As related to the team, an operator would be sent to the roof in the middle of the night with a "half-mile lantern" to report when the plume of white "smoke" stopped issuing from the jet exhaust, thereby signifying a satisfactory UF_6 negative.

Procedures available for team review from the 1970s and 1980s do not address the use of jets to obtain UF_6 negatives. Where discussed in the procedures, the use of jetting was limited to static or sweep purging of isolated process gas equipment after a satisfactory UF_6 negative had been achieved and confirmed by sampling. Procedures from the late 1980s and 1990s do not address jetting at all, relying instead on evacuated surge drums and wet air pumps to perform HF static and sweeping purges, with essentially no release of UF_6 to the environment.

In the mid-1980s, several Paducah process improvement projects focused on ways to reduce cascade vent emissions. Chief among their recommendations for reducing UF_6 emissions to the environment was discontinuing using process building air jets for evacuating cascade cells. Although using the jets was not banned as late as April 1986, efforts were under way to demonstrate and establish alternatives and to revise procedures to avoid jet use. However, as late as September 1988, the procedure for "Startup of the Cascade" still stated that the building purge jets could be used for evacuating air.

No interviewee remembered the jets being used after the mid-1980s, and many believed it was no longer physically possible to use the jets. Upon inspection, it was discovered that the jet isolation valves could still be opened by inappropriate manual operation. Even without such manipulation, the purge jet piping presents a potential unmonitored path for release of UF_6 through leaks or inadvertent valve manipulation. USEC promptly issued two assessment and tracking reports, established additional administrative controls, and recommended cutting and capping the lines to the jets after assuring no nuclear criticality safety concerns. Although the flat and expansive roof of each process building is treated as a contamination control area, no special posting was observed in the vicinity of the jet exhausts that would indicate higher contamination levels, suggesting that the process building purge jets have not been used in a long time.

3.2.3 UF_4 and Metal Production

Along with the enriched uranium produced at Paducah, the Plant also produced uranium metal. These operations were conducted, upon completion of construction in 1957, in a small complex of buildings on the eastern side of the Plant known as C-340. In June 1962, operations were significantly scaled back. A second campaign began in 1967 and continued until 1977. From 1978 to 1982, the building served as a shipping point for UF_4 green salt. This area of the Plant was one of the least desirable job assignments for workers. The work was hot and dirty, high levels of airborne uranium were often present, and HF was frequently released in small quantities from various points. In 1962, a worker was killed in C-340 and another seriously injured from burns received during a furnace accident. Another worker was severely injured by anhydrous HF during a maintenance operation on an HF transfer line. Although it could not be confirmed by records, at least one operator interviewed believed that the worker died later as a result of his exposure; the investigation team did not find any documentation to support this belief. After 1982, the building was used for utilities maintenance, training classes, security exercises, and prototype valve tests. In 1994, the building was fenced and locked, and it is currently accepted into the decontamination and decommissioning program, but receives only routine surveillance and maintenance. Decontamination and decommissioning will not take place until after shutdown of the gaseous diffusion plant.

Metals production involved several steps, each with its own unique hazards. The first step in the process was powder production. UF_6 process gas reacted with hydrogen in a heated tower to produce UF_4 powder (green salt) and HF. The HF was vented from the tower through a collection system that condensed the HF to a liquid, which was stored in a tank. Periodically, the tank would be pressurized with nitrogen and transferred to Building C-410 for use in feed production. Fluoride releases from production of UF_4 are likely responsible for most of the ecological damage that occurred in the northeast quadrant during early operations at the Plant. C-340 was capable of producing several thousand pounds of HF daily when operating. Even if the Plant recovered 99 percent of the HF produced, as reported by a former building supervisor, a significant amount of HF would have been released.

Army assault masks and respirators were normally available to operators and were required for many of the operations. Entries in operating instructions and reports from workers indicated that these requirements were not always followed or adequately stressed by foremen. Consequently, operators in C-340 were frequently placed on restriction due to the intake of uranium compounds, especially in the powder areas on the fifth and sixth floors of the tower building.

The reaction towers were a primary source of airborne uranium. Operating at pressures above atmospheric, any leak in the system could release fine dust and HF. The building had two vacuum systems (dust collectors), one for general cleaning and one for uranium, with hose ports that could be connected in many locations. These hoses were frequently placed near leak sources to minimize releases, but they were not always effective. To meet production needs, the towers would sometimes be operated with leaks that approached or exceeded the capture capacity of the vacuum system. Very early on, the general cleaning system became contaminated when it was used while the uranium system was shut down for maintenance.

The UF_4 green salt fell out of the bottom of the tower into a series of hoppers and screws used for powder transfer. It could then be placed into drums for sale or storage or sent to the next step. UF_4 was removed from the hoppers at the bottom of the reaction towers. This operation created large amounts of airborne uranium dust. Within four months after startup, respirators were identified as being required for drumming operations.

Metals were produced by reduction of the green salt to uranium metal with magnesium. The first step in the process was preparation of a "bomb" liner. Magnesium fluoride (MgF_2) was placed in a steel shell and "jolted" (mechanically agitated) to pack the refractory and remove any voids. The next phase of the operation involved blending measured quantities of green salt with measured quantities of powdered magnesium metal, and then pouring this mixture into the bomb liner. A refractory cap was then poured, and a lid was bolted to the top of the charged bomb. The charged bomb was then transferred to an induction furnace where it was heated to the point where the magnesium reduction started.

The primary hazard associated with this part of the process was exposure to the airborne uranium dust during weighing, blending, and pouring. Respirators were required very early during the initial production operations. The bombs also presented a significant hazard from burning magnesium and molten uranium metal. A phenomenon described as "burnout" and "lid fires" occurred infrequently when the refractory liner was not correctly prepared. For example, burnouts occurred when the burning magnesium came in contact with the steel shell, melting through the shell and releasing the bomb contents into the furnace. Lid fires were similar, but occurred at the lid rather than the side of the shell. Such an occurrence led to the fatality in March 1962. Burnouts resulted in significant contamination of the furnace refractory and would normally require the entire furnace to be relined. Removing the old refractory lining generated large quantities of dust; personnel repairing the furnaces would not always wear proper respiratory protection and consequently might have been exposed to high levels of uranium oxides from the refractory dust.

After the "bomb" was cooled, it was sent to the breakout area where the lid was removed, the shell was inverted, and the contents were dumped onto a grating, referred to as a "grizzly." The slag material, at this point a hard ceramic material, was broken into smaller pieces by beating it with a hammer. The pieces were dropped through a grating into a jaw crusher and sent to the slag plant. This operation was among the dirtiest jobs in C-340. Operators reported (with confirmation from supervisors) being completely covered with black dust. Respirators were required and generally worn, although the extent of dust and contamination probably exceeded the protection they provided. The metal ingot, referred to as a derby, was freed from the slag and could be "roasted" to oxidize the surface and loosen any remaining slag. Loose oxides that fell from the derbies during roasting were collected, put in drums, and sent to a burial yard. After roasting, the derbies were cleaned by hand in a cleaning booth using power brushes and grinders to remove any remaining slag. While not as dirty a job as the breakout and slag crushing, this job also generated high levels (i.e., periodically above Plant allowable limits) of airborne contamination.

After cleaning, the derbies could be shipped directly or sawed into smaller shapes, depending on customer requirements. Derby sawing generated large amounts of uranium metal "saw dust," which burns readily in air. Consequently, saw dust was collected in drums of oil and kept covered. Despite these measures, uranium metal fires were common (daily or weekly), resulting in high levels of airborne uranium oxides.

The MgF_2 reaction product remaining in the bomb was captured, crushed, ball milled, and then sized to be recycled as refractory. Although primarily a hands-off operation, it generated significant quantities of dust. Over time, the slag became contaminated with significant quantities of uranium oxides (several percent) that could have contributed to worker intakes. Reject slag (too small or too large) was collected in a hopper, then periodically drummed and sent to the northeast corner of the Plant site. It was not clear from either operators or log reviews whether those drums were stored and later removed or dumped and buried.

C-340 was also capable of re-melting the uranium derbies and casting specific shapes; operations were conducted in a furnace with a controlled atmosphere. Graphite crucibles were used to receive the molten uranium. The primary hazard associated with these operations was cleaning the crucibles between pours. Over time, oxides of uranium and beta-emitting uranium decay products would impregnate the crucible. Since crucibles were cleaned by hand, operators would have received radiation dose to their hands, arms, and fingers. No dosimetry was worn by operators that would have measured these extremity exposures.

3.2.4 Recovery Operations

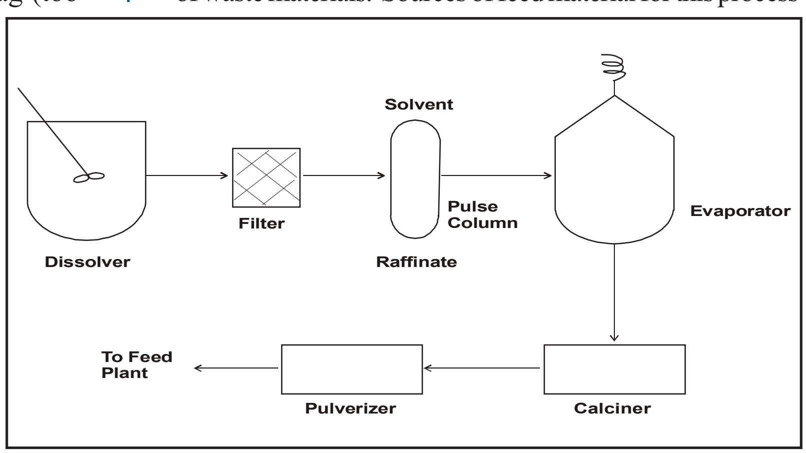
- *Uranium Recovery*
- *Neptunium Recovery*
- *Technetium Recovery*

Throughout PGDP's operational history, uranium has been recovered from waste streams and recycled through the enrichment process to minimize loss of this valuable material. Neptunium and technetium were also recovered during early Plant operations to meet high demands for these materials. Recovery operations reduced the releases of uranium, neptunium, and technetium to the environment but produced high concentrations of radioactive materials in Plant processes that posed significant occupational hazards to Plant workers.

The source of neptunium and technetium at PGDP was feed material from uranium recovered from spent reactor fuel at the Hanford and Savannah River sites. The AEC understood that fission products and transuranics could present health problems to gaseous diffusion workers and set limits on the amount of that could be present in feed materials. The chemical separation processes at Hanford and Savannah River removed most, but not all, of the transuranics and fission products.

Uranium Recovery

Uranium recovery facilities in C-400 were used to chemically separate and recover uranium from a variety of waste materials. Sources of feed material for this process



Uranium Recovery Process

included: fluorination tower ash, sintered metal filters, decontamination solutions, UF_6 scrubber solutions, particulates from ventilation filters and vacuum cleaners, laboratory wastes, and materials from spills. Before the mid-1970s, a complex uranium recovery process in Building C-400 separated uranium from waste and scrap materials, concentrated it, and converted it to an oxide. The process included the following steps: dissolution of feed materials, filtration, solvent extraction in pulse columns, concentration by evaporation, and denitration to an oxide.

The uranium recovery system was not leak-tight, and leaks were common. Operators were instructed to mop spills from process equipment but acknowledged that some spills probably went down the drain. Steps were taken to control operators' exposure to process materials. Routine surveys were conducted to monitor the concentration of radioactivity on surfaces and in the air in C-400, and the health physics staff recommended changes in work practices based on the results of these surveys. Uranium recovery system operators were provided coveralls. Rubber gloves and respirators were available, but their use was not strictly enforced; they were generally worn at the discretion of the operators. The aqueous raffinate from solvent extraction columns that contained neptunium-237, thorium-234, palladium-234, and technetium-99 was discharged to the environment.

In the mid-1970s, the solvent extraction process for uranium recovery was replaced with a simpler precipitation and filtration process. Steps in this new process included: dissolution of feed materials in nitric acid, addition of lime to precipitated uranium, and recovery of precipitated uranium as a filter cake.

The filtrate, containing low concentrations of radionuclides, was discharged to the environment. Sludges and filter cake were buried on site if uranium concentrations were low or sent to Fernald if concentrations were high enough to warrant further recovery.

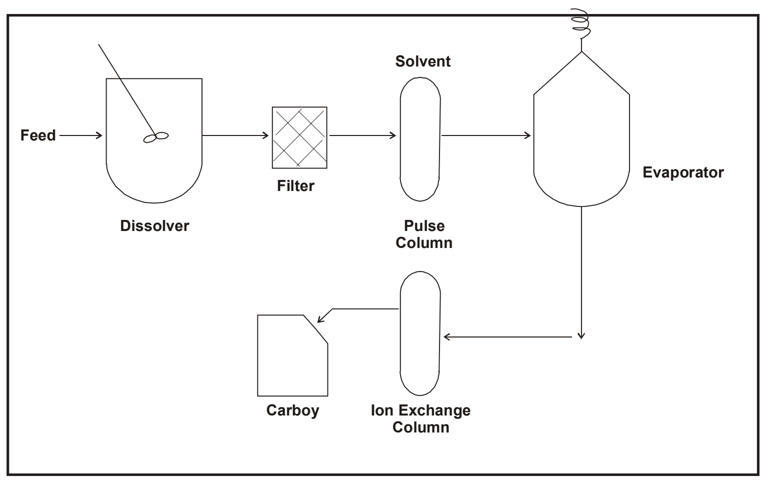
Neptunium Recovery

Soon after neptunium was identified at Paducah in 1957, the AEC placed a high emphasis on its recovery. A neptunium recovery process was developed at ORNL, and began operation at PGDP in November 1958 in Building C-400. The process used a solvent extraction and evaporation method to recover and concentrate neptunium from receiver ash and cylinder heels:

- Receiver ash and solids that settled from cylinder wash water were dissolved in a nitric acid solution.
- Solids suspended in this solution were removed by filtration and discarded as solid waste.
- The filtrate was processed through solvent exchange pulse columns to separate uranium, thorium, and neptunium. (These columns were originally located in Building 710, Room 32, and may have been moved to C-400 sometime after July 1959.)
- Raffinate from these columns was dumped to the building drain if it contained uranium and neptunium concentrations less than 500 ppm and 0.2 mg/L, respectively.
- Uranium and thorium were recovered for future use.
- The neptunium solution was concentrated to about 20 to 25 g/L by evaporation.
- The concentrate was sent to a laboratory in Building 710 for additional separation and concentration in ion exchange columns. The final product was siphoned into glass carboys on the loading dock at C-710.

The highest concentrations of neptunium at PGDP were associated with neptunium recovery processes that operated intermittently from 1958 until the late 1970s. These processes separated and concentrated neptunium from receiver ash, cylinder wash water, and MgF_2 pellets used in technetium traps. One liter of neptunium recovery product contained about one curie of radioactivity. Processing systems were complex, leaks were common, and respirators were not always worn.

The relatively high hazards associated with neptunium were understood at Paducah as early as 1959, and special practices for handling neptunium solutions and neptunium-contaminated equipment were



Neptunium Recovery Process

recommended. Recommendations included: using non-breakable containers; maintaining tight systems; keeping lids on containers; preventing bubbling, frothing, or spraying of solutions; using rubber gloves; washing the gloves before using them in other areas; using respirators (or assault masks) for welding or burning; and performing alpha surveys of all equipment removed from neptunium processing areas.

The limited information available indicates inconsistent implementation of these recommendations. For example, a recovery system operator did not recall using a survey meter. He said that the resin exchange columns were made of glass and that they broke from time to time, discharging their contents to the Building C-400 drain. He was concerned that the system was not sufficiently leak-tight to contain hazardous materials.

Estimates show that 4.289 kg of neptunium were recovered using the above process (3.215 kg from heel washings and 1.074 kg from ash). This process was discontinued in October 1961, after MgF_2 traps were determined to be a more productive method of recovery. The recovered neptunium was shipped from the site. The neptunium recovery system was removed from the Plant in the late 1970s.

The processing of solutions containing neptunium though the solvent extraction and ion exchange system produced raffinate and wash solutions with some neptunium remaining. Solutions with neptunium concentrations greater than 2 mg/L were either reprocessed or stored. Seventeen drums of waste from the neptunium recovery program remain stored on site today. Solutions with a neptunium content less than 2 mg/L were discharged to the environment using building drains. Estimates indicate that approximately 200 grams were discharged in this manner.

A second neptunium recovery process was used briefly after 1961 to recover neptunium from MgF_2 pellets that had been removed from technetium traps in the feed plant and cascades. Although the traps were originally installed to adsorb technetium, they were also quite effective in adsorbing neptunium. The pellets were vacuumed from traps in the feed plant and cascades and transported to Building C-400, where neptunium was removed by a chemical stripping process. Approximately 33 grams of neptunium were recovered by this method before recovery operations were terminated at the site in the mid-1960s.

Neptunium recovery was classified at the time, and only individuals with a need to know were familiar with the details of the program. For security reasons, neptunium was known by the code name "Trace," and most Paducah workers were not aware of its presence at the Plant. Operators and maintenance mechanics interviewed during this investigation could recall no training on the hazards associated with neptunium before the late 1980s, although it is possible that such training was provided. A 1962 training manual for chemical operators stated that "Since neptunium is more active than uranium, greater precautions should be taken to prevent its inhalation and any spills should be cleaned up immediately to prevent the material from becoming airborne. In addition, an ultrafilter chemical respirator, rubber gloves and acid goggles should be worn when transferring solutions."

Technetium Recovery

Technetium-99 is a fission product that was received at Paducah in recycled feed from Hanford and Savannah River Sites. Technetium passed through the Paducah cascade as a volatile compound of fluorine, depositing on internal surfaces of the cascade and contaminating the enriched uranium product. The AEC did not specify a limit for technetium in UF_6 feed but controlled the concentration of technetium indirectly to about ten ppm by limiting gross beta from fission products.

A demand for techtetium-99 in the early 1960s prompted Paducah to begin a campaign to recover 25 kg of this material from various effluent streams. In 1960, a process was begun to recover technetium from UF_6 cylinder wash water and from the raffinate generated during neptunium recovery. Process steps included precipitation and removal of uranium from these solutions by adding sodium hydroxide. The aqueous superannuate was processed through an ion exchange column and elutriated with nitric acid to produce a concentrated solution of technetium that was shipped to ORNL. Although technetium was not a significant radiological hazard during most PGDP operation and maintenance activities, this concentrated form presented a more significant hazard.

Technetium traps were installed in the feed plant and in the cascades in 1961 and 1963, respectively, to reduce contamination of the enriched uranium product. A small amount of technetium was recovered from these traps in the early 1960s. Technetium was leached from the pellets in a dissolver in C-400 and potassium hydroxide was added to precipitate the uranium. The solution was then filtered and processed in the same manner discussed above.

In the mid-1970s, a process was developed and implemented at PGDP to remove technetium from aqueous waste streams for the purpose of environmental protection. Technetium in superannuates following uranium precipitation was removed as an insoluble solid through the use of iron sulfate as a flocculating agent.

3.2.5 Smelting

Three smelters operated in C-746A, including a nickel induction furnace, a reverberatory furnace used to melt clean aluminum, and an aluminum sweating furnace. Little data on smelter operations at the Plant was available to the investigation team because records were stored in contaminated waste drums or were removed by another DOE team investigating scrap metal recovery at the Plant. A 1972 study of radionuclides in scrap indicated the potential for airborne concentrations of uranium during loading of melting pots; however, no uranium fumes were detected during alloy melting or pouring.

3.2.6 Maintenance

Aluminum Pouring Operations

- *Major Component Maintenance*
- *Cylinder Cleaning*
- *Cylinder Valve Replacement*
- *Filter Bag Replacement*
- *Cooling Tower Chemical Treatment and Repair*

Maintenance tasks often presented the most likely opportunities for worker exposure to the unique hazards of the gaseous diffusion process. Process piping penetrations, work with solvents, component disassembly and cleaning, and cylinder valve replacements were commonplace activities. Additionally, much of the work was conducted in open bay shops without controlled ventilation. Consequently, workers in the vicinity of, but not directly involved with, specific maintenance actions could have been exposed to hazardous conditions beyond their control or knowledge.

Major Component Maintenance

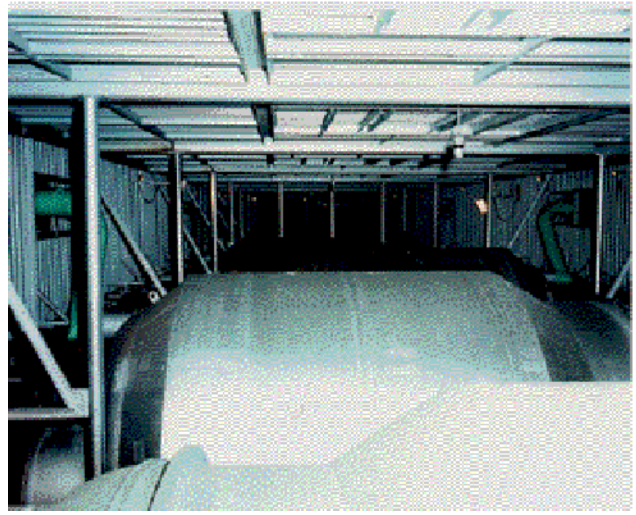
Maintenance on major components in the cascade (compressors, converters, and process block valves) presented some of the most significant opportunities for exposure of maintenance personnel. Work on these components required that they be removed from the system, cleaned, rebuilt or repaired, and then reinstalled. In order to remove these components, process operators isolated and bypassed the cascade cell containing the component, reduced the UF_6 within the cell to less than 10 ppm equivalent at atmospheric pressure (a UF_6 negative), and then purged the cell to minimize HF and UF_6 exposure of workers involved in opening, maintaining, or modifying cell components. Once a satisfactory UF_6 negative and HF purge was accomplished and the pressure of the isolated cell was raised to atmospheric pressure with dry air, the isolated cell was turned over to process maintenance for cell opening and disassembly.

Workers opening a cell and dismantling cell components could be exposed to UF_6, HF, UO_2F_2, and to a lesser extent, transuranics and certain fission products, such as technetium. Maintenance personnel would initially make a small hole or cut in the process gas piping to confirm that cell pressure was at approximately atmospheric pressure. A 1989 procedure for maintenance personnel entitled "Penetration of UF_6 Piping Systems" required all personnel within 15 feet of the opening to be wearing full-face respirators with GMHF-C canisters, and to wait for industrial hygiene/health physics personnel to provide guidance on when they could remove the respirators. One interviewee described times during CIP/CUP when "smoke" (UF_6) released from compressors as they were cut out of the process gas system would obscure visibility. Work would resume once the process building exhaust fans dissipated the cloud. To prevent the potential spread of radioactive contamination, the same maintenance procedure required all openings into components to be covered as soon as practicable after removal from the process gas piping.

Compressors were transported from the process buildings to Buildings C-720 and C-400 for "000" and

"00" sizes, respectively ("000" and "00" are size designations, with "000" being larger). The compressors were then disassembled into major components within pits, the parts transported to Building C-400 for spray washing to remove uranium deposits, the rotor and stator relocated as required for deblading within C-400 and C-410, respectively, and all the reusable washed parts returned to their respective maintenance buildings for modification, refurbishment, degreasing, and reassembly. Once reassembled, the compressor openings were covered for transportation to storage or reinstallation. Converters were transported from the process buildings to Building C-409 for decontamination. The barriers were then taken to Building C-400 for washing, disassembly, and scrap recovery. Following washing in C-400, the converters were modified, refurbished, and reassembled in Building C-720. Prior to removal from the system, block valves were slightly opened (where possible), inspected, cut out of the system, lifted free of process piping, decontaminated, covers installed, and shipped to C-400 for preliminary disassembly and decontamination to the limits allowed in C-720. Once decontaminated, the valve was again covered and transported to C-720 for final repair and reassembly, and staged in the process building for reinstallation.

UF_6 as a gas or solid was sometimes trapped within components and would be released when finally exposed to air. Remaining solids would become airborne, particularly when pneumatic tools were used. Because of the resulting white smoke and pungent odor, these releases were apparent to both the mechanics and the other workers in the area, resulting in some instances of spontaneous evacuation of the area. As one interviewee described it, "smoke out conditions" were commonplace, and workers donned respirators if they couldn't breathe. The job steps most likely to present these inhalation hazards included removal of the stator/rotor stack from the outer compressor shell, removal of the compressor stub shaft, removal and disassembly of shaft seals, compressor rotor deblading, removal of converter internal hardware in C-409, barrier disassembly in C-400, cutting of the valve purge pigtail, opening or removal of the bonnet flange of a stuck-shut valve, and disassembly of the stem gland of a valve with a leaking bellows. Although respirators were specifically recommended for these activities, their use was sporadic, as reported by those interviewed and by industrial hygiene/health physics personnel who occasionally monitored airborne contaminants and made recommendations for worker protection.



Converters

The potential hazards are best illustrated by an early 1970s event recounted by one interviewee. He was involved in removing the top of a 20-inch G-17 valve using air-arcing near the pump shop (at the edge of the C-720 fabrication shop). The valve was tagged, indicating that it had been decontaminated in C-400. However, when the top flange of the valve was lifted with the crane, gray smoke came pouring out and continued to smoke, affecting much of C-720. The crane operator (directly above the valve), who reportedly balked at evacuation because he had seen it happen before, passed out and had to be rescued. Before his evacuation, the interviewee and his supervisor, without any respiratory protection, tried to close the opening by using sledgehammers. Finally, they too had to leave the building without stopping the smoke, due to burning eyes and throats. Three individuals (including the interviewee) exceeded the threshold action levels for uranium on urinalysis. Although the next 24-hour samples were reportedly clear, all urine was collected from the individuals for the next eight weeks. A similar event occurred in C-720 in February 1986, when 100 people were evacuated and 40 were put on urinalysis, with seven on recall. Respirators were not worn for this work, and the JHA did not address the hazards of contaminated valves.

Compressor mechanics were also exposed to TCE during component degreasing. One interviewee indicated that while cleaning compressors, it was common to use TCE bare-handed (to reach into components) without respiratory protection. Rubber gloves were available for handling TCE, but he did not use them. Reportedly, workers did not have masks available for degreasing work, and he would often feel lightheaded from fumes.

During the 1970s and early 1980s, AEC/ERDA/DOE and Union Carbide undertook the most extensive of several campaigns to improve PGDP technology and exchange or replace aging equipment. All of the industrial, radiological, and chemical hazards discussed for normal compressor and converter maintenance were present, with the additional challenge of a demanding, manpower-intensive schedule for completing each task. Dedicated cell change-out teams were established to remove and replace cell components almost continuously. Tools for cell change-out were pre-positioned. Cell housings were opened even as operators worked to establish a UF_6 negative. Modified and refurbished compressors and converters were pre-staged in the process buildings with proper orientation, ready for emplacement once the cells were cleaned out and new saddles and support systems installed. Original cell components were disassembled, cleaned, modified, refurbished, reassembled, conditioned, and pre-positioned for another cell change-out, even as the original cell was being repopulated. Operators were prepared to perform leak checks, pre-operational tests, and cell startup as soon as maintenance approved the release of the various permits establishing their safety envelope. Many workers were hired to support CIP/CUP, but reportedly they did not get the same level of training as older workers; they were told to rely on more experienced workers while learning their jobs, principally through on-the-job training.

Practices to protect personnel from excessive exposure to airborne radioactivity in the shops evolved over time. In 1959, recommendations were made for additional dust control measures to minimize the potential for exposure. These included use of continuous water mist spray during removal of the compressor stack and collection of the resulting wash water, wearing air respirators in the C-720 pit area until lower air counts were obtained, disassembling compressors to three main components and removing them to C-400 for spray decontamination, wetting down compressor spool piece bolts prior to air tool removal, decontaminating compressor mating pipe flanges in the original cell area prior to grinding, and removing slag. Despite ongoing work to improve the local area exhaust in the C-720 converter shop, health physics also recommended thorough wetting of disassembly work while workers continued to wear respirators. In 1962, at least one sample of dust from C-400 compressor deblading showed 90 percent of its radioactivity from transuranics and fission products. Although dust was removed by vacuuming, the rotor was not wetted to control dust as required. Respirator use was noted to be “as required.”

By the mid- to late 1970s, health physics surveys of work practices, fixed and portable continuous airborne activity monitor analysis, and contamination surveys were routinely documented. During this period, the Health Physics and Hygiene Department was aware of the presence and increasing amounts of transuranics and fission products. The Health Physics and Hygiene Department emphasized the importance of respirator use during certain disassembly steps, encouraged the repair and improvement of local air exhaust systems, criticized the use of portable air movers for ventilation, and pushed for better tooling to minimize dust production. The Health Physics and Hygiene Department also noted inadequate respirator use, reportedly prompting correction by work supervisors.

As CIP/CUP progressed in the late 1970s, so did the degree of sophistication of the health physics survey reports. Levels of uranium, neptunium, plutonium, thorium, technetium, and uranium daughter products were routinely reported and discussed, with accompanying recommendations. Contamination surveys just outside the compressor pit area prompted a call for better housekeeping practices. Continuous air samples near the pit and adjacent machine shop indicated no significant spread of airborne radioactivity to the surrounding area. During obviously dirty job steps, respirators were reportedly used; however, respirator use was still observed to be lax during many short-duration tasks. A December 1975 shop memorandum required the use of respirators and local area exhaust for welding, cutting, grinding, buffing, and use of certain power tools on specified components.

In 1976, the Health Physics and Hygiene Department concluded that methods established to that date for control of personnel exposure during compressor maintenance were adequate, but emphasized the importance of maintaining these practices. The practices included respiratory protection using one-quarter or one-half respirators with radioactive aerosols or radionuclide filter cartridges for certain specified jobs; vacuuming loose material, dust deposits, and spilled material; wetting down compressor stacks with water before placing them in the disassembly stand; collecting wash water for delivery to C-400; and decontaminating compressor parts in C-400 after stack disassembly. Despite these recommendations, problems with respirator use continued to be reported (though less often). The Health Physics and Hygiene Department reminded management of the importance of respirator use while disassembling converters in C-409, particularly in light of the high levels of transuranics detected in solid deposits within the converters. Concern was again expressed over the lack of adequate local air exhaust in the C-409 converter shop areas where dust-producing activities were performed.

In 1977, continued attempts to establish adequate local area exhaust and stop the use of the air mover in the compressor pits were at first unsuccessful. The Health Physics and Hygiene Department recommended continued efforts to stop dust generation at the source as an ALARA principle. Further, the Health Physics and Hygiene Department recommended immediate action to provide adequate exhaust ventilation, supported in part by breathing zone air samples exceeding Plant guidelines for uranium, neptunium, and thorium by factors of 40, 22, and 15, respectively. The Health Physics and Hygiene Department also recommended continuing use of the vacuum collector system for loose deposits, keeping compressor components wet during use of pneumatic tools, and providing local air exhaust to all disassembly steps where practical. The Health Physics and Hygiene Department noted that additional local area exhaust was being designed and would be installed as soon as possible in C-409 to support converter disassembly work. The Health Physics and Hygiene Department also recommended the use of water sprays in C-400 to control dust during barrier disassembly. Respirator use was apparently improving during this period, as indicated by interviews and Health Physics and Hygiene Department reports.

In 1978, The Health Physics and Hygiene Department commended the shops for use of low-speed, high-torque wrenches and ventilation uprating by extending the vacuum system to an adapter on the pneumatic wrenches. Collecting the dust at the source of generation was noted to decrease concentrations of uranium by 98 percent and neptunium by 91 percent. However, individuals noted during interviews that this fix did not survive the rigors of compressor maintenance work and was later abandoned. No replacement mitigation equipment was remembered by those interviewed or observed in the C-720 pit by the investigation team.

Health physics surveys of the C-720-C converter shop in 1980 for the CIP/CUP indicated that Plant guides for airborne alpha activity were exceeded for uranium by a factor of 1680, neptunium-237 by a factor of 2121, plutonium-239 by a factor of 2483 and thorium-230 by a factor of 55. Even using conservative protection factors for the respirators used, these exposure levels were significant.

The levels of airborne contaminants resulting from these maintenance activities, supervisors' failure to enforce proper use of respirators, and employees' failure to wear respirators when required contributed to the high proportion of personnel who were on restriction for elevated levels of uranium in their urine and were CIP/CUP workers. For example, a sample of exposure records from the first half of 1978 shows that 20 of 29 urine samples exceeding the PGDP investigation level were from individuals involved in CIP/CUP activities.

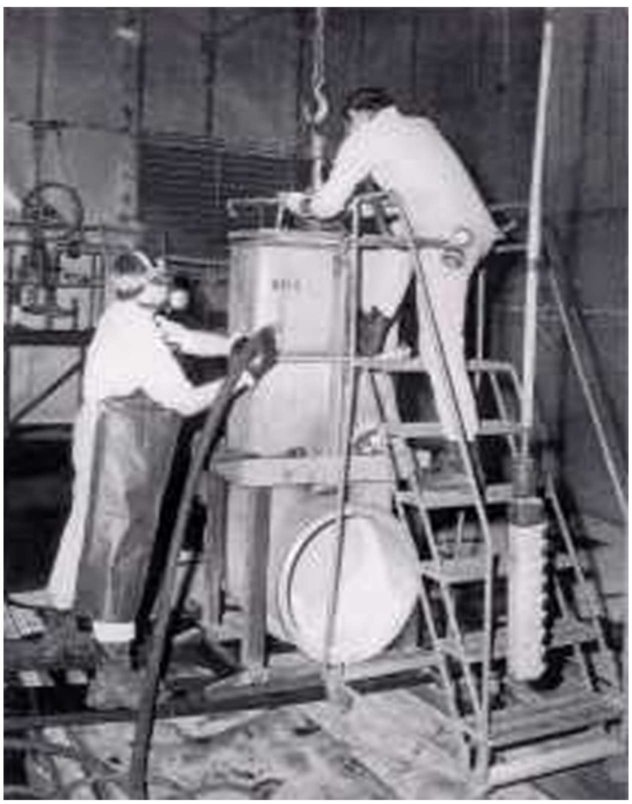
Cylinder Cleaning

With repeated reuse, UF_6 cylinders collected deposits that did not completely volatilize in the autoclave. Periodically these deposits, called "cylinder heels," had to be dissolved and removed, and the cylinder was then cleaned, refurbished as necessary, re-inspected, hydrostatically tested, and weighed for subsequent use. Cylinder heels were composed of corrosion products, uranium salts and oxides, and transuranic and uranium daughter product compounds. With regard to the neptunium contaminants of the process gas, most of the plutonium and technetium was volatilized to the cascade, while most of the neptunium remained behind in the cylinder heels, creating a significant radiological hazard. Cylinder cleaning was performed at Building C-400, where the heels were dissolved and the rinse water was collected in a large pan. Cylinder rinse water was used as the principal source for neptunium and technetium recovery in the late 1950s and early 1960s. Otherwise, liquid effluents were pumped to the tank farm for feed into one of the digesters, while workers shoveled sludge, which collected in the pan, into containers for further processing or disposal. Sludge reportedly was shoveled approximately once a month; workers were limited to 15-minute exposures, and it usually took four workers to complete the task. The Health Physics and Hygiene Department closely monitored worker activities.

Two documented beta overexposures occurred at the C-400 cylinder wash facility in the first quarter of 1968. The estimated exposures were 24 and 36 rem, whereas the quarterly limit for skin of the whole body was 10 rem. The two workers were standing in a metal tray used for collecting cylinder rinse water that was emitting several hundred rads of beta radiation. Interviews and documents indicated that in the early 1950s a decision was made that extremity monitoring was not required because it was felt that these doses were not likely to exceed 2.5 times the whole body exposure. The evaluation for the cylinder wash overexposure incident failed to completely evaluate this event and determine extremity dose.

Cylinder Valve Replacement

Each UF_6 cylinder is equipped with a manual cylinder valve. Occasionally, these valves were identified as defective and would be replaced. According to procedures that existed in the 1970s, any UF_6 cylinder was required to cool at least five days before its valve was replaced. Cylinders known to be above atmospheric pressure after the minimum cooling period would be cold-burped and further cooled, if necessary, with cold water. If pressure above atmospheric could not be relieved, the cylinder would be turned over to Chemical Operations in C-400 for special handling, which involved dedicated tanks used to further cool the cylinders to promote UF_6 solidification and pressure reduction.



Valve Maintenance

Cylinder valves were normally replaced in C-310, C-315, or the tails storage area. Interviewees also described valve replacement during the 1960s in the vicinity of C-400, after icing down cylinders. One interviewee indicated that until the mid-1970s, defective UF_6 cylinder valves were routinely replaced "on the fly" with the mechanic standing upwind and any escaping smoke going the other way. The applicable maintenance procedure in the 1970s and 1980s required respiratory protection to be worn; however, interviews suggest that although gas masks were available, they were not always utilized until a release of HF ("blow-out") occurred. The defective valve was slightly unscrewed to confirm that air would be drawn into the cylinder. Once a vacuum was confirmed, the valve was quickly removed and the replacement valve installed. If positive pressure was evident on the first attempt to change the valve, the original valve would be retightened and another attempt scheduled in not less than 24 hours. If positive pressure was still noted on the second attempt, the valve would again be retightened and the cylinder would be turned over to Chemical Operations in C-400 for special handling. Once the valve was successfully replaced with the proper torque and thread engagement, the defective valve was decontaminated and appropriately dispositioned. The new valve and cylinder combination was then inspected and pressure tested to confirm a successful repair.

In the event of a major UF_6 release from an open or broken cylinder valve, procedures in the 1970s provided guidance that personnel should be immediately evacuated from the area of the release, emergency assistance summoned, and available emergency ventilation maximized. Caution was provided to stay upwind of the release; that personnel required to enter the release area must wear Gra-Lite, Acid Master, or impermeable suits with self-contained air masks; that exposed personnel should report to the dispensary as soon as possible; and that all water in the area should be considered contaminated with HF and neutralized with soda ash. The emergency squad was expected to apply water to the cylinder to promote cooling and knock down the UF_6 cloud, stop the leak with a wooden plug or tape if the valve could not be shut, and (if that didn't work) cover the cylinder with a prefabricated box from C-310, filling the box with dry ice and covering with a tarpaulin. Once the cylinder could be cooled to the point of drawing a vacuum, the defective valve was removed and a replacement valve installed.

A Three-Plant UF_6 Cylinder Handling Committee convened in the mid-1970s and made a number of recommendations that affected PGDP cylinder valve replacement activities. Among the recommendations implemented by 1986 were the sole use of new valves for valve repair or replacement, modification of procedures for valve replacement to drop reference to freeze-down tanks at C-400 (although the tanks existed, onsite supplies of dry ice were insufficient for emergency or contingency use), and revision of site procedures to address the use of updated emergency release securing equipment and new studies indicating that water should not be used on liquid UF_6 releases.

The principal hazards to workers engaged in cylinder valve replacement were both radiological and chemical, involving the potential for inhalation of and exposure to UF_6, HF, and UO_2F_2. One person recounted an event where pressure in a 2-ton cylinder was found to be above atmospheric while he was attempting to clear ice from the cylinder-valve hole threads in preparation for inserting a new valve. He reportedly grabbed an available army assault mask and drove a wooden plug into the hole to stop the release. No exposure data specific to this mid-1960s event was obtained by the team. Another interviewee remembered several instances in the 1960s and 1970s when he and his partner were replacing 14-ton cylinder valves; UF_6 apparently had not completely solidified in the cold bath, and he and his partner were covered in yellow material. Both were wearing respirators and subsequently took showers to remove surface contamination. He believed that they were frisked after each UF_6 cylinder event and that such frisking was a normal follow-up to such an event. These descriptions of cylinder valve leaks while replacing valves were typical of a number of interviews.

Filter Bag Replacement

Filter bag houses existed in several buildings for both ventilation and dust collection. Replacing the bags in these systems was described as very dusty and the dirtiest work that could be assigned. Workers were periodically directed to replace the filter bags when needed because of excessive dust loading. Reportedly, filter bags needed to be changed once or twice a month, but the same individuals did not always get the assignment due to shift work. In the 1950s, workers reportedly secured the evacuation jet, donned army assault masks and a company-provided coat over their company-provided coveralls, draped towels over their heads and around their necks, taped their sleeves up, opened the enclosure, released the hose clamps in sequence, and carefully put the dusty bags in large barrels. Operators then vacuumed the remaining dust from the enclosure, and maintenance installed new filter bags, closed the enclosure, and started the evacuation jets again. The job frequently took half the day and had to be halted for lunch. Although workers were reportedly allowed to change into clean coveralls for lunch or after the job was done, most of those interviewed suggested that they seldom changed. Workers described blowing their noses after changing filters and obtaining a black discharge despite having worn the respirators. In the early 1960s, concern about radiological exposure resulted in reducing workers' times in the area to no more than 15 minutes, significantly less than previously allowed.

Some workers in C-340 and C-420 described changing filter bags without respirators or anti-contamination clothing. Sometimes they reportedly used small paper masks, even though they came out covered in green dust. If procedures existed for changing filter bags, workers did not recall seeing them. Other individuals remember occasional periods between 1968 and 1977 when the C-410 or C-420 bag houses were bypassed straight to the atmosphere whenever they got plugged or needed changing. Hazards to workers included airborne UF_4, uranium oxides, process dust, and alpha and beta contamination. Workers wore dosimetry devices and were subject to monthly bioassays. Respirators occasionally became plugged and were sometimes not used. When filter bag replacement activities were evaluated by health physics, they were found to be dusty and often presenting the potential for elevated external exposure. Air samples reviewed were found to be above the PGDP MPC.

Cooling Tower Chemical Treatment and Repair

The cooling towers were treated annually with fungicides, principally to protect wooden components from fungal attack and deterioration. Inspections in 1958 showed significant internal fungal attack. Several different chemical treatments were tested, some of which involved arsenic and chromate compounds. Additionally, much of the original redwood was replaced with pressure treated lumber. Finally, the commercially available wood preservative/fungicide pentachlorophenol (PCP) was selected.

As originally practiced, fungicide spraying involved operators climbing within the cooling tower structure with ladders, work platforms, safety ropes and guidelines, and finding perches on cooling tower structural members to stand on while directing the spray. The workers wore protective clothing and breathing apparatus. This difficult task was made more hazardous by the risk of slipping and falling. At least one worker fell within the confines of the cooling tower during repair operations. In the early 1980s, a modified in-place fungicide treatment process was developed that did not require any climbing within the cooling tower, thereby significantly improving safety and reducing the difficulty of the job.

Cooling Towers

During interviews, some former workers expressed concern about their activities on and in the dry cooling towers without respirators or special protective clothing, having previously seen the fungicide spray team in their air-supplied neoprene suits. A 1981 JHA for "Routine Cooling Tower Inspection" does not identify any inhalation or skin absorption hazards for cooling tower repairs, but does require that gloves be worn to avoid splinters. The 1987 version of this JHA requires, in addition, the use of a respirator with a GMC-H cartridge due to the possible presence of legionnaire's disease bacteria or asbestos fibers, the latter more likely in older cooling towers where the asbestos fibers have become friable. In neither JHA is there any mention of residual PCP as a potential hazard to individuals climbing on or in the cooling towers. No JHA or monitoring data was identified for carpentry work in the cooling towers.

3.2.7 Operations and Maintenance Summary

It is clear that during operations and maintenance activities at PGDP, many situations allowed workers to be exposed to both radioactive and chemical hazards. While workers were exposed to higher levels of radiation, especially beta radiation, than they were previously made aware of, monitored exposures were tracked and (with documented exceptions) did not exceed the standards of the time. In some situations, workers could have exceeded the standards, and those situations were not adequately monitored; consequently, some workers might have exceeded acceptable doses established for that time, especially to extremities such as hands and feet. Workers' failure to properly use PPE and supervisors' failure to enforce the use of PPE, especially respirators, contributed significantly to these radiation and chemical exposures. Finally, production needs in many aspects of operation and maintenance further contributed to worker radiation and chemical exposures. Examples included operating equipment with leaks, removing equipment without adequately venting the systems or removing deposits, and releasing uranium materials to the air without use of confinement systems.